Using Agent Based Distillations to Model Human Intangibles for Dismounted Infantry Combat

Ruth Luscombe[1]*, Helen Mitchard, Andrew Gill*
Defence Systems Analysis Division, DSTO

ABSTRACT

The impact of human behaviour will remain an important factor in determining the outcome of battles in the future. Even with advanced sensors and weapons systems, understanding the psycho-physiological state of the soldier is of vital importance to combat analysis. In the near future it is expected that simulations will continue to provide much of the data for strategic and capability planning for future forces. Therefore it is all the more important to include human modelling in at least some of those simulation tools.

MANA is an Agent Based Distillation (ABD) developed by the NZ Defence Technology Agency (DTA). ABD's are simulation tools based on cellular automata models, whereby a collection of agents interact with each other using a set of parameters and decision making algorithms. Unlike the detailed behaviour required to run simulations such as CAEN and CASTFOREM, the behaviour of MANA agents is defined by inputting a small set of parameters that characterize their goals and capabilities. One of the features of MANA is event-driven transitions that allow predefined changes in the agents' behaviour in response to certain events.

Human behaviour is influenced by complex interactions between people and their environment. We have selected a set of behaviour moderators; cohesion, fatigue, morale and suppression with the intention of modelling the interactions produced by human behaviour in dismounted infantry combat. We moved from qualitative definitions to quantitative models by conducting a literature review and interviewing subject matter experts. This gave us data from which we were able to produce functions modifying certain parameters of the combat agents in such a way that is representative of real human behaviour.

This paper outlines the way in which we have attempted to represent human behaviour using the constructs of MANA. Also, we consider approaches to validating the model output and the addition of further intangible qualities to this model.

[1] Presenting Author

1. Introduction

> *"When human roles are involved and human participants are not used, it is important to provide models of human behaviour in order to ensure realistic outcomes." [1]*

The majority of current combat simulations do not represent human behaviour at all, and very few have rules based on doctrine that mimic ideal decisions [1]. Human behaviour includes planning, decision making, sensing, situation awareness and physical movement. These tasks are all affected by behaviour moderator variables; individual characteristics such as stress, personality, cultural values and experience.

To model human intangibles there are many software tools that could be used. Mainly they focus on the behaviour of individuals. One of the attractions of using a cellular automata approach is the focus, not on the individual but on group behaviour. Another attraction is the higher level of abstraction that can be used. However other tools may prove easier to validate.

We interviewed subject matter experts to determine the fundamental behaviour moderators and used this data, and that from a literature review, to synthesise definitions for these terms. The main challenge was finding sufficient information to develop a computational model. Most of the literature available, barring that on the effects of sleep loss, contains only qualitative data. For quantitative data we relied mainly on information derived from structured interviews.

Once constructed, the computational model will be implemented in MANA [2], a third party combat distillation made available by its developers at the DTA in New Zealand. To verify the implementation of the model we will run a dismounted infantry attack scenario. A more difficult task will be to assess the validity of the model output.

2. Mana

MANA is an Agent Based Distillation (ABD), a type of cellular automata model inspired by Project Albert[2], of the Marine Corps Combat Development Command (MCCDC). Project Albert is intended to explore combat as a complex adaptive system, investigating such properties as emergent behaviour, non-linearity, and intangibles through the application of ABD's [3].

The main benefit of using ABDs as a simulation tool is the quick set up and run time enabling a large number of parameters to be examined quickly [3]. MANA was specifically chosen because it is an advanced model and because developers at the DTA have made their code and expertise available to us in order to facilitate the development of a human intangibles model.

The simple behaviour of the entities in MANA provides a convenient environment to introduce human behaviour moderators. Agent behaviour is defined by a number of input parameters which describe the movement selection criteria, weapon characteristics and physical capabilities assigned to each set, or squad, of agents. These input parameters are variables which define the behaviour of the agent.

A scenario is composed of squads of agents who interact with each other and with their environment. The battle environment is a 200x200 terrain grid that may include features such as vegetation, waypoints and impassable obstacles. Another feature of MANA is a list of event triggers which can bring about predefined changes in the parameter values that define the agents' behaviour.

At each time step in a scenario run, each agent is selected in random order to execute the standard move procedure, making use of the assigned parameter values. Figure 1 shows the standard move procedure with the addition of the behavioural model in bold.

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[2] www.projectalbert.org

```
BEGIN Move Procedure
  update behavioural variables based on event triggers
  IF Rate of Incoming Fire > 0 THEN
    update behavioural variables based on suppression table
  ELSE
    update behavioural variables based on morale value
  ENDIF
  IF unsuppressed THEN
    calculate P(Lapse)
  ELSE
    P(Lapse)=0
  ENDIF
  update behavioural variables based on cognitive fatigue
  IF P(Lapse)>Random(0,100) THEN
    step in same direction as previous move
  ELSE
    observe enemy and friendly entities within visual range
    initiate interactions
    shoot at enemy agents within firing range
    calculate penalty value of all possible moves
    select best move
  ENDIF
  update position on battlefield grid
END Move Procedure
```

Figure 1: Agent move procedure with Behavioural Model in Bold

3. Data Collection

To scope the behaviour moderators and identify those that are included in this model, a literature review was conducted. The focus of the review was on articles in psychology journals, specifically *Military Psychology* and *Pyschological Review*, looking for experimental data or behavioural models. Our main conclusion was that qualitative material is readily available, but the quantitative data required to develop a computational model is rare. Behavioural modelling to date consists of a small number of application specific models, underlining an obvious need for more models dealing with human behaviour moderators in combat.

In the areas where quantitative data was lacking we constructed our models by interviewing subject matter experts (SMEs). Insight gained through unstructured interviews often presented us with useful domain information relating to military doctrine as well as drawing our attention to details that we may have otherwise overlooked. When specific data was required, structured interviews provided us with much of the information used to develop the functions in this model.

However, the value of interview data should not be overestimated. Data acquired through interviews is still for the most part qualitative [4]. This data was obtained from subject matter experts drawn from the Australian Army. The human behaviour model constructed for the agents is based upon arbitrary levels that best represented the data. After the implementation of the intangible model in MANA, the more difficult task will be validating the output.

4. Definitions of Intangibles

The model is based on an understanding of how human behaviour can influence combat performance. In defining these terms; cohesion, morale, fatigue and suppression, we wanted to find an appropriate level of abstraction for a model in MANA. These definitions are important for they show the factors that we concentrated on and the data involved can also be used to reflect on whether the observable behaviour of the agents corresponds to our knowledge of these factors. In the following sections we define these terms before discussing their implementation.

4.1 Cohesion

Cohesion is an influential factor in the maintenance of good morale and is also a buffer against battle stress [5, 6]. Mael and Alderks [7] define cohesion as a bond developed between group members and also with the leaders of that group. These bonds are developed through shared hardship, risk and fear. Cohesion relates strongly to morale. In fact, a loss of morale will correspond to breakdown in cohesion [6].

4.2 Morale

As defined in the Fundamentals of Land Warfare [8], morale is the Army's will to fight. It is the intangible quality which encompasses motivation, courage and endurance.

Morale is an idiosyncratic trait influenced by cultural background, training, leadership, experience and individual difference [2, 9]. Consequently it is extremely difficult to create an accurate model of morale using mathematical constructs. To quantify morale, we must determine which entities and events affect the morale of a combatant.

4.3 Fatigue

Fatigue causes fundamental changes in system level efficiency [10] due to factors such as intense emotional strain, strenuous physical exertion, poor and inadequate diet, environmental conditions and sleep loss [11]. MANA does not contain the fidelity to respond to factors such as environmental conditions, diet or physical exertion. Owing to the availability of data, the fatigue component of this computational model is concentrated on performance changes resulting from periods of total sleep deprivation.

Sleep loss causes notable performance decrements in error rates, missed signals, response times, vigilance and event-paced weapon handling [9, 12, 13]. The two main sources for these performance changes are lapsing and cognitive fatigue.

Lapsing, similar to micro sleeps, is the occurrence of brief trance-like states that are responsible for some of the variation in response times and error rates. Lapsing becomes more frequent during prolonged periods without sleep [13]. In addition an increase in cognitive fatigue is inferred when performance between lapses also degrades as sleep debt accumulates [10, 12]. This cognitive fatigue causes less significant changes to the performance of the soldier, but has been included for completeness.

Fatigue effects can be variable between individuals. Also these effects can be temporarily ignored with sufficient levels of motivation or excitement.

4.4 Suppression

All definitions of suppression relate volume of fire from one side and degradation of performance of the opposing side [14]. Suppression is defined in the US Army Field Manual [15] as

> *"Temporary or transient degradation by an opposing force of the performance of a weapons system below the level needed to fulfill its mission objectives."*

Suppression behaviour is a response to the perceived threat of enemy fire. Perceived threat is influenced by the psycho-physiological state of the soldier and the volume of incoming enemy fire. When enemy fire is not considered to be a threat then the activities of the combatant are not restricted. When the fear of personal injury is great, the combatant seeks to reduce his personal risk by reducing his target profile and restricting his movement.

Perceived threat also influences the duration of suppression. Kubala & Warnick [14] conceded that variable duration suppression was not only a more intuitive way to model suppression but was also more accurate. Levels of suppression are defined by the degree of restriction to suppression behaviour, such as the functions of look, fire and move, as experienced by the suppressee.

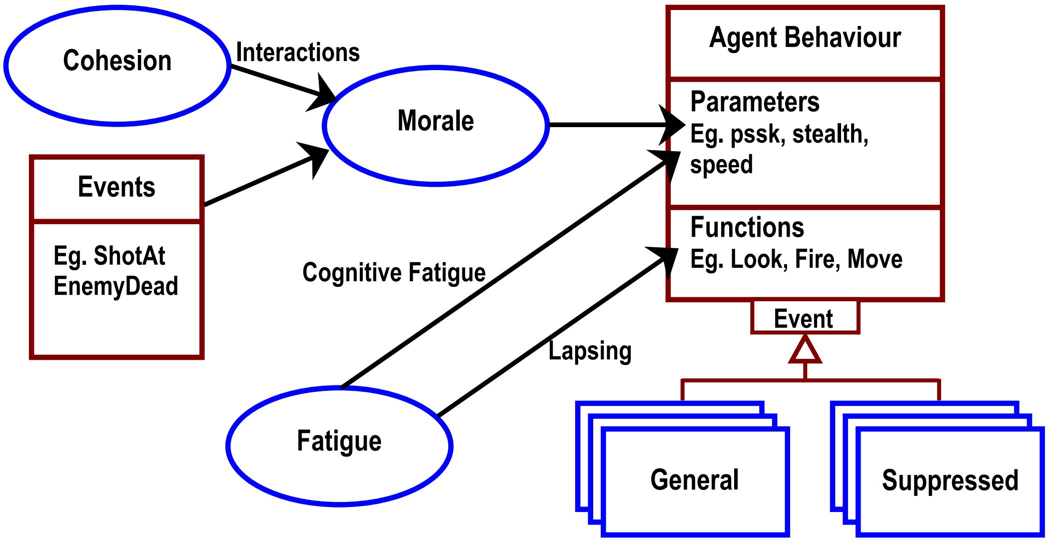

Figure 2: Overview of Intangible Model in an Individual Agent

5. Model

Using the definitions listed in Section 4, we will now outline their proposed implementation within MANA.

Agent behaviour is defined by functions and parameters. Functions implement the rules of agent behaviour and parameters hold the values representing personality and capability variables.

Figure 2 shows an overview of the construction of the proposed model. Fatigue, cohesion and morale are the factors which moderate agent behaviour. Suppression is a modelled as a collection of agent behaviours.

Two types of behaviour have been defined in Figure 2. Firstly, suppressed behaviour is a type of behaviour that is triggered by an incoming fire event. The rate of that incoming fire and the current morale determine the level of observable suppression in the agent. Secondly, general behaviour encompasses all other types of behaviour including default behaviour and other user defined behaviours.

Interactions between allied agents are used to represent cohesion. These interactions incorporate a system feedback loop between agents. The morale value of each agent affects the likelihood that it will initiate an interaction. The morale of both interacting agents influences the value that the interaction will add to the morale of the receiving agent.

The morale variable assigned to each agent fluctuates as a result of events and interactions. The morale value acts as a modifier on agent parameters in conjunction with the effects of cognitive fatigue. Morale has the effect of changing parameter values producing behavioural changes analogous to stress and fear, reduced will and motivation.

Fatigue is implemented in two tiers; lapsing and cognitive fatigue. Both are measured in terms of hours awake. The lapsing component affects the sequence of functions that are carried out by an agent during a move. Cognitive fatigue, like morale, depresses performance by changing certain parameter values.

We have attempted to model human behaviour at a reduced level of complexity using simple mathematical functions. When we validate the model we will look at the interaction of all the equations to see if the model faithfully represents human behaviour.

5.1 Cohesion

Cohesion is based upon the belief that interactions between group members can have a reinforcing effect on morale and that interactions between highly cohesive group members may overcome the net negative affect of stressful events in the battlefield.

An interaction can be initiated by any agent on the battlefield. Interactions in MANA involve a sender agent, who is able to generate an interaction trigger, and a receiving agent who reacts to that trigger, as outlined in Figure 3.

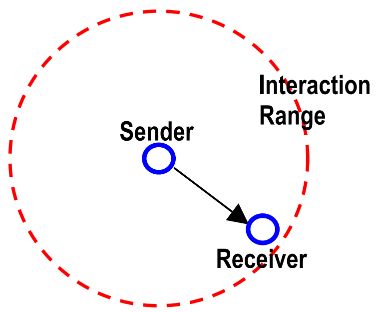

Figure 3: Interaction between agents

An agent can only send an interaction trigger within a certain range and within a certain probability. These parameter values are subject to morale decrements. An agent with higher morale is more likely to interact with other agents and over a greater distance.

Table 1: Morale gained by receiver of interaction

Sender's Morale Level (0 to 100%) \ Receiver's Morale Level (0 to 100%)				
0	-2	-2	-1	0
	0	1	2	1
	1	1	3	2
100%	1	2	4	2

We have modelled the effect of an interaction on the receiver as an amount of morale is gained or lost. The data in Table 1 was derived from interviews with subject matter experts. Interview data infers that the value of an interaction is dependent upon the current morale level of both interacting agents. Although cohesion has the ability to improve morale, interactions with individuals who have very low morale may exert a negative influence.

5.2 Morale

Morale is represented as a numeric quantity that varies between zero and 100%. High values correspond to high morale.

The morale of an entity is affected by events and interactions that occur during battle. Section 5.1 on Cohesion details the effect of interactions between agents.

Of the events which are likely to occur in MANA, we have identified a subset of events that are appropriate stimuli for changes in morale. Using interview data collected from subject matter experts, we ranked the events in Table 2 on an arbitrary scale from –5 to 5. Each of these events sends a software message to the agent and adjusts the morale variable by the appropriate amount.

Morale value modifies a number of behavioural parameters. Generally, when morale is in the medium to high range, the agents' behaviour remains unchanged. When morale falls below a certain level simple functions simulate a gradual decline in will and effectiveness of the combatant. The agents become more fearful of enemies and less efficient with their weapons. Low morale also reduces the likelihood that agents will interact with each other.

Table 2: Event triggers and Morale values

Event Name	Morale Change (%)
Reach Waypoint	+2
Reach Final Waypoint	+4
Take Shot	+1
Enemy Injured	+3
Enemy Killed	+5
Shot At	-2
Injured	-5
Friendly Agent Shot At	-1
Friendly Agent Injured	-3
Friendly Agent Killed	-4

5.3 Fatigue

Fatigue is measured as a function of time awake. Two new input parameters are required in order to record the duration of sleep deprivation periods; one to scale the number of MANA time steps that make up an hour, and a second parameter that specifies the number of hours since waking for each squad of agents.

A Lapse state is a non-responsive state which prevents the agent from performing the standard move procedure. Because lapse duration is measured in milliseconds and the scale of a single MANA time step would be in hours or minutes, therefore the lapsing function has been implemented probabilistically and is detailed in Figure 4.

Using the SILCS functions [13] derived from experimental data, we can estimate the probability that an agent would be suffering from a lapse at each time step. In the event of a lapse occurring, the agent is not able to observe or react to changes in the environment and thus is assumed to move in the same direction as in the previous time step.

Cognitive fatigue causes performance decrements that are independent of the performance errors caused by lapsing. These sleep loss decrements cause gradual reduction in effectiveness of weapon handling and decision making. Cognitive fatigue decrements act upon a subset of the parameters affected by morale.

Figure 4: Pseudo code for Lapse procedure

```
Calculate P(Lapse)
IF P(Lapse)>Random(0,100)
THEN
  step in same direction
  as previous move
ELSE
  execute standard move
  procedure
ENDIF
```

5.4 Outline of Agent Behaviour

The intangible factors that we have included in this model are intended to capture some of the performance variation that is evident in real battles. We are attempting to model combatants whose behaviour is modified by the events in battle.

The intangible factors change the efficiency and effectiveness of the combatant modelled.

Table 3: Behaviour Parameters influenced by Intangible factors

Parameter	Cohesion	Morale	Cognitive Fatigue	Suppression
Pssk[3]	✔	✔	✔	✔
Targets per Step	✔	✔	✔	✔
Stealth	✔	✔	✔	✔
Move Speed	✔	✔	✔	✔
Precision[4]	✔	✔	✔	
Interaction Range	✔	✔		
Prob Interaction	✔	✔		
Move Selection Criteria	✔	✔		

[3] Pssk: Probability of a Single Shot Kill
[4] Precision: measure of randomness in movement decision algorithm

Table 3, above, lists the parameters of the MANA agents that are affected by the different behaviour moderators. Morale, cognitive fatigue and suppression all affect a similar set of parameters and in addition cohesion feeds back into morale. For example cognitive fatigue causes a gradual reduction in reaction time, vigilance, shooting accuracy and decision making. Similiarly low morale, when under fire, causes a greater degree of observable suppression behaviour and longer recovery time.

5.5 General and Suppressed Behaviour

General and suppressed behaviours have been classified as two different behaviour types because they are affected differently by the interaction of morale and enemy fire. General behaviours are not expressed when under enemy fire. Suppressed behaviours are the product of interactions between enemy fire and morale resulting in physical restriction and other effects. Another difference is that the lapsing phenomena does not occur to an agent in a suppressed behaviour state. This is supported by the view that

> *"Fatigue can be quickly ignored in a state of emergency or an excess of enthusiasm." [10]*

Four levels of behaviour are defined for use in this model; Unsuppressed, Suppressed, Pinned, and Cowering. Unsuppressed behaviour is any of the general agent behaviours. Suppressed behaviours include suppressed, pinned and cowering, which entail increased levels of physical restriction. When suppressed, the agent takes cover but continues to return fire at a reduced rate. Under heavy fire, the agent becomes pinned and is unlikely to move or return fire. Finally, when morale is extremely low and incoming fire is high, the agent does not move or fire, this agent is said to be cowering.

The value of morale and the rate of incoming fire determine which of the suppression behaviours is expressed by the agent (Table 4). Incoming effective fire is measured by the number of 'shot at' events recorded by an agent in a single time step. A new variable has been introduced which records this value for each agent at each time step. The parameter values for the remaining types of suppressed behaviour are based on the parameter values assigned to the 'shot at' state in MANA.

Table 4: Suppression decision table

Morale	Rate of Incoming Fire: <1				Max
≤100%	**U**	**U**	**S**	**S**	**P**
≤75%	**U**	**S**	**S**	**P**	**P**
≤50%	**U**	**S**	**P**	**P**	**C**
≤25%	**U**	**P**	**C**	**C**	**C**

Legend

U: Unsuppressed
S: Suppressed
P: Pinned
C: Cowering

The behaviour of the suppressed agent is reassessed at the beginning of each time step. As the morale of the agent and the rate of incoming fire changes, the level of suppression may change. Further incoming shots also increase the duration of suppressed behaviour thus representing variable duration suppression as recommended by Kubala & Warnick [14]. The agent will only revert to unsuppressed behaviour if the duration of the suppressed state expires with no additional incoming fire events.

6. Verification and Validation

Specifically the verification process for this model is tuning the values in Table 1 and Table 2 to avoid misrepresentation of the effects of morale. Arbitrary values were selected to populate these tables of events and interactions making them the weakest part of the model. Recording the morale value for each agent as a time series should reveal the interactions between the factors of the model.

As with any computational model, it is important to validate the output of the model. Part of the model validation will be carried out by comparing the results from multiple scenario runs with and without the human intangibles model. Common attrition based MOE's will provide a means for comparing the two sets of results. Also we will rely on advice from subject matter experts to determine if this model produces sensible output.

7. Future Considerations

Criticisms that this model is a simplistic attempt to address the complex issues of human behaviour in combat are valid but fail to address the scale of the task. This task has encouraged the use of approximations as a pragmatic choice . The initial design phase, presented in this paper, has focussed on the intangible factors suggested by SMEs as more important. Listed in this section are some of the factors that were omitted from this design cycle and are under consideration for future implementation.

The next stage of this work is to finalise the functions for the model and implement them in code. Following this we will run a test scenario of a dismounted company attack on a dug in platoon and attempt to obtain useful data.

Vertical cohesion, that is cohesion between leaders and subordinates, has been omitted. The quality of leadership has a great influence on the cohesion of a group [7]. The role of the leader is to maintain morale and cohesion in times of stress [6]. A leader appointed to a group of agents would, in general, have a greater impact on the morale of his soldiers and be able to rally troops suffering poor morale.

The impact of extreme levels of morale can contribute to panic or heroic behaviours. Due to the simple nature of our model, we have not included these types of behaviour. We also chose not to model the behavioural changes which affect an injured soldier. These are non-recoverable states that also influence other members of the group.

This model addresses only fatigue caused by sleep deprivation. Other types of fatigue have an important influence on the combat performance of a soldier, such as physical fatigue and combat fatigue. Further, the sleep deprivation model that we have used is only valid for predicting performance under conditions of total sleep deprivation. The effects of napping and other fatigue counter measures have not been addressed.

8. Summary

This work addresses the lack of human behaviour modelling in closed-world combat simulations. Since much of the force development and acquisition process relies on data from simulations, it is important to include models of human behaviour in at least some combat simulation tools Modelling of human behaviour is infrequent and rarely addresses the modelling of human 'intangibles'. This is despite the fact that Napolean's saying

> *"the moral is to the physical as three is to one"*

is often quoted.

The intangible factors that have been selected, and their definitions, were obtained from the results of a literature review. In addition, the lack of quantitative data in the field of human sciences has meant much of the data used in the construction of this model has been obtained though a series of interviews with military personnel posted at the DSTO, Edinburgh. We are in the process of implementing this model in MANA.

The focus of this study has been to introduce human intangibles into modelling. MANA provides us with an opportunity to model military scenarios and extract meaningful insights that can be utilised in the analysis of dismounted infantry combat. Cellular automata tools such as MANA offer a level of abstraction that reduce the scale of the task.

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